CHAPTER 4

Decarbonization Policies Around the World

FIGURE 4.1 SHOWS the share of global emissions of carbon dioxide from the world's top 20 emitters, led by China and the United States, as well as the total emissions of 193 other countries not listed individually.[1] The top 20 emitters were responsible for about 80 percent of total global emissions in 2006.[2] The other 193 countries were responsible for about the same amount as China or the United States. This chapter will survey aspects of domestic decarbonization policies of several of these countries. What we will see is that despite significant effort in many countries, no country has yet figured out how to decarbonize its economy at a pace beyond historical rates, much less the very aggressive rates needed to achieve ambitious emissions-reduction targets. The chapter will then conclude by explaining the significance of the survey for national and international climate policies.

Using the same ratio that was presented at the end of Chapter 3 of metric tons of carbon dioxide emissions from the burning of fossil fuels for each $1,000 of GDP in 2006, Figure 4.2 shows this ratio for each of the top 20 emitting countries.[3] The countries are ordered left to right from highest to lowest emitters (as in Figure 4.1). France, with its large use of nuclear power, has the most carbon-efficient economy of the top 20, and South Africa, with its heavy reliance on coal-powered energy, has the least carbon-efficient economy, emitting more than six times as much carbon dioxide per unit of GDP than does France.

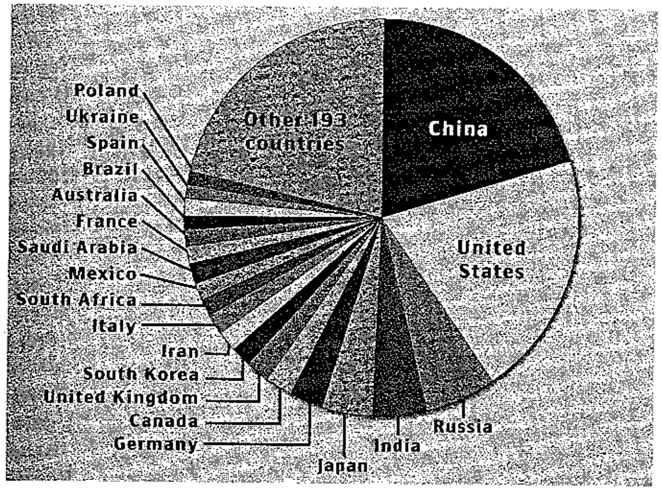

FIGURE 4.1 Global carbon dioxide emissions, 2006. Source: U.S. Department of Energy.

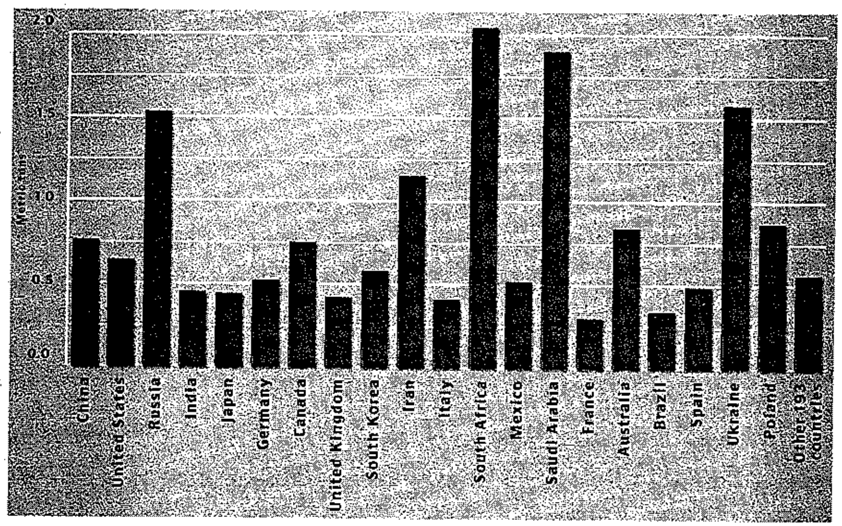

FIGURE 4.2 Metric tons of carbon dioxide per $1,000 2006 GDP. Source: U.S. Department of Energy and A. Maddison.

Let us next look more closely at a few of these countries. In absolute terms Japan, India, and the United Kingdom had relatively more carbon-efficient economies than did Germany, which was somewhat more carbon efficient than the United States, which in turn was more carbon efficient than China and Australia. As we will see, the reasons for

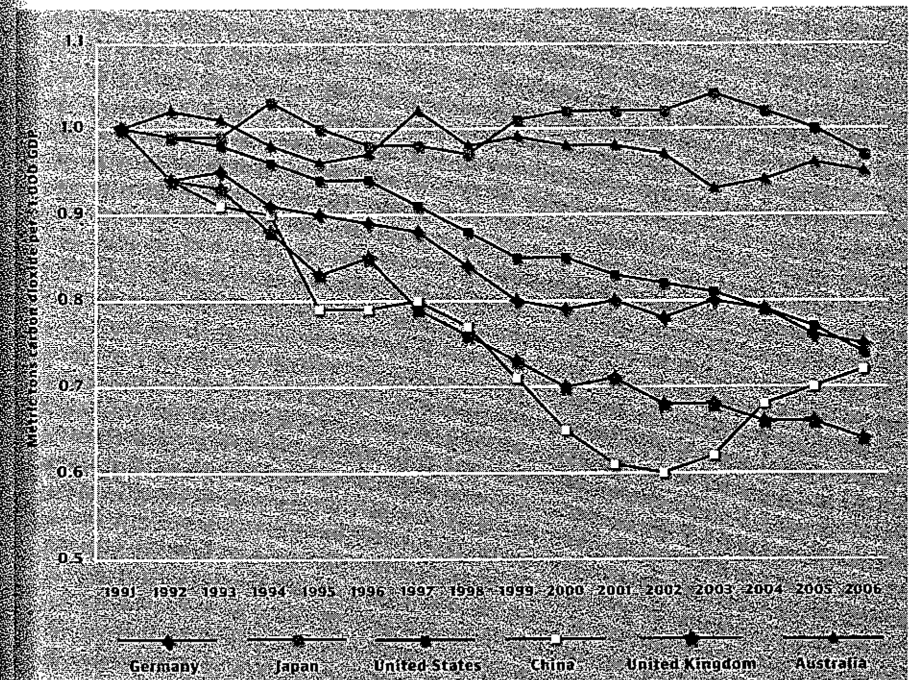

FIGURE 4.3 Relative improvement in CO_2 per GDP, 1991–2006. Source: Author's calculations.

these differences have everything to do with context and history and nothing to do with climate policies.

For each of these six countries, Figure 4.3 shows the relative improvement in carbon dioxide per unit of GDP for the period from 1991 (chosen as the first full year of German reunification) through 2006. The figure shows several interesting trends. First, Japan, even with its relatively low carbon intensity in 2006, has seen little change over a decade and a half, an issue that we will revisit shortly. Germany and the United States start at different absolute levels, but their respective pace of decarbonization was almost identical, despite the fact that the two countries had very different policies and politics during that time period; for instance, Germany signed on to the Kyoto Protocol of the Framework Convention on Climate Change in 1997, whereas the United States rejected it. The U.S. and German experiences indicate that there are many different paths to decarbonization. China experienced a fast rate of decarbonization in the 1990s as its economy grew rapidly due to the effects of globalization. This trend abruptly reversed in the 2000s as China sought to keep pace with an incredible increase in demand for energy, which it met by dramatically expanding its use of carbon-based fuels.[4] Australia saw little change in the carbon intensity of its economy over this period. Let's now look at the policies of several countries in a bit more detail and explore what they signify for future efforts to accelerate decarbonization.

United Kingdom: The Climate Change Act of 2008

On November 26, 2008, the British government enacted the Climate Change Act of 2008, mandating national emissions reductions. In December of that year the United Kingdom's Committee on Climate Change (created by the act) released a report recommending that national greenhouse gas emissions be reduced by at least 80 percent by 2050 and by 34 percent by 2022 (or 42 percent if an international agreement on climate change is reached) from a 1990 baseline. The report argued that this amount of emissions reduction is achievable at an affordable cost of between 1 and 2 percent of GDP in 2050.

In 2006 the UK produced 0.42 metric tons of carbon dioxide for every $1,000 of GDP. Figure 4.4 shows decarbonization in the UK from 1980 to 2006. It also shows the required annual average rates of decarbonization of the UK economy from 2007 to 2050 (for a 2 percent assumed annual GDP growth rate) implied by a target of an 80 percent reduction in carbon dioxide emissions from 1990 levels. The carbon intensity of the UK economy would have to reach a level of 0.02 to 0.05 metric tons of carbon dioxide per $1,000 of GDP by 2050, for faster (3 percent) and slower (1 percent) rates of economic growth respectively. Figure 4.4 also shows the same information for 2022 implied by the target of a 34 percent reduction in carbon dioxide levels from 1990. The carbon intensity of the UK economy would have to reach a level of 0.17 (for 3 percent annual GDP growth) to 0.24 (for 1 percent annual GDP growth) metric tons of carbon dioxide per $1,000 of GDP by 2022, from 0.42 in 2006.

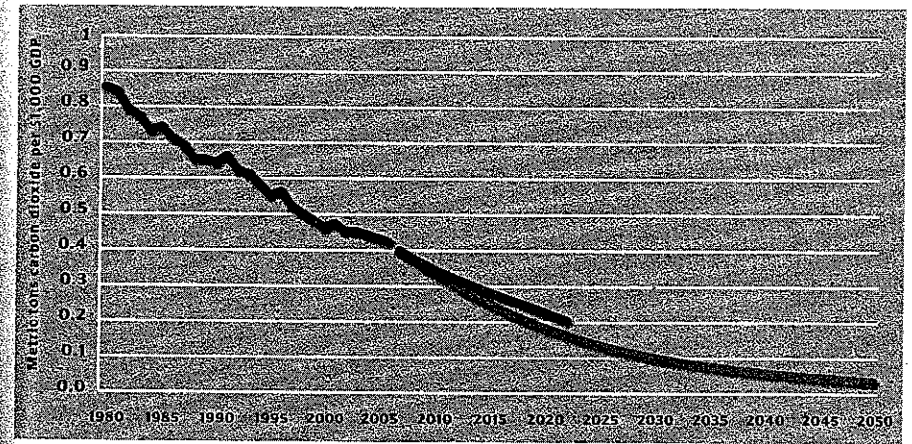

FIGURE 4.4 Historical and implied decarbonization of the UK economy. Source: Author's calculations.

The implied rates of decarbonization of the UK economy for the curves in Figure 4.4 are 4.4 percent per year for the 2022 target and 5.5 percent for the 2050 target. These numbers are substantially higher than the rates of decarbonization observed from 1980 to 2006 and 2001 to 2006, as summarized in Table 4.1.

Achieving the ambitious targets for emissions reductions set forth in the UK Climate Change Act will require rates of decarbonization much higher than have been achieved in any major economy in recent decades. The Climate Change Committee has not addressed explicitly whether this is a reasonable goal. However, in an interview, Julia King, vice chancellor of Aston University in Birmingham and member of the Climate Change Committee, responded to an earlier version of this analysis by saying that in fact the scenarios provided by the committee have "been tested for do-ability." King apparently meant theoretical technical "do-ability" (along the lines discussed in Chapter 2 in the section "Do We Have All the Technology We Need?"), as she also explained that achieving the targets has both technical and political challenges, with the latter difficult to overcome: "I think you really do need to take due account of the fact that most people who are putting together targets and timetables are doing this on the basis of a lot of research into potential scenarios. It's another issue turning that into policy, for governments, and it's

TABLE 4.1 Annual rate of decarbonization of the UK economy observed (first two columns) for 1980 to 2006 and 2001 to 2006, and implied by the 2022 and 2050 targets assuming 2.0 percent future GDP growth

	1980–2006	*2001–2006*	*2007–2022*	*2007–2050*
Actual	–1.9 percent	–1.3 percent		
Implied by targets			–4.4 percent	–5.5 percent

very easy for all of us who don't have to be elected to say, 'This is how I would do it,' and I have a lot of sympathy for our politicians, because they are dealing with extremely selfish populations."[5]

A key aspect to effective policy implementation is that policies must be not just technically feasible but also socially and politically acceptable. For instance, it is one thing to say that deployment of, say, dozens of nuclear power plants is technically possible; it is quite another to achieve it in practice. Regardless of the technical arguments for theoretical "do-ability," the targets of the Climate Change Act fail the test of practical "do-ability," as we will see.

One important reason for the decarbonization of the UK's economy is that manufacturing has declined as a portion of its economy, from 33 percent in 1970 to 13 percent in 2007.[6] A onetime switch from coal to gas—the so-called dash for gas motivated by Margaret Thatcher's policies with respect to unions and state control of energy—also played a role. Reliance on such actions in the future is obviously not a sustainable route to decarbonization. Further, there is no recent precedent among developed countries with large economies for the sustained rapid rates of decarbonization implied by the Climate Change Act. Such rates necessarily must be several times greater than observed in the UK in recent decades.

France, which of the major economies has the lowest ratio of emissions to GDP, provides a good point of comparison for the UK. France has achieved its relatively low level of decarbonization due to its reliance on nuclear power for electricity generation. France achieved an average rate of decarbonization of about 2.5 percent per year from 1980 to 2006, but achieved only about 1.0 percent per year from 1990 to 2006. It took France about twenty years to decarbonize from 0.42 metric tons of carbon dioxide per $1,000 GDP, the level of the UK in 2006, to 0.30 metric tons of carbon dioxide per $1,000 GDP.

In order for the United Kingdom to achieve the very low ratios of carbon emissions to GDP implied by its policy targets, it must at some point reach France's ratio of 0.30 along the way. For the UK to be on pace to achieve the targets for emissions reductions implied by the Climate Change Act, its economy would have to become as carbon efficient as France's by no later than 2015 (depending on economic growth). See Figure 4.4 above and, in particular, the year in which the implied decarbonization curve crosses 0.30. In practical terms this level of decarbonization of the UK economy could be achieved, for example, with a level of effort equivalent to building and operating about forty new nuclear power stations by 2015, displacing coal- and gas-fired electrical generation.[7] An example of the sort of nuclear power station used in this analysis is the Dungeness B station in Kent, on the southeast coast of England.[8]

Following that achievement, to meet the 2022 target the UK would then have to decarbonize by an additional 33 percent, that is, from 0.30 metric tons of carbon dioxide per $1,000 GDP, to 0.20 metric tons. The analysis of the Climate Change Committee is largely consistent with this conclusion, explaining that achievement of the 2050 target would require that all UK electricity generation be completely decarbonized by 2030.[9]

Upon reading an early draft of this analysis, Colin Challen, member of Parliament from the Labor Party and chairman of its All Party Parliamentary Climate Change Group, commented to the BBC that he agreed with the analysis, making reference to the government's recent decision to expand Heathrow Airport despite the fact that an expansion would lead to increased emissions from greater air travel:[10]

> This [analysis] raises questions which I do not think have been factored into the thinking behind the Climate Change Act. The task [of cutting emissions by 80 percent from 1990 levels by 2050] is already staggeringly huge and, as we have seen, well beyond our current

political capacity to deliver. Heathrow is a prime example of ducking the responsibility. It is hard to see any tough choices being made in the current climate. A greater population implies more embedded carbon-dioxide emissions in imported goods, but the climate change committee is only empowered to consider domestic emissions.[11]

Given the magnitude of the challenge and the pace of action, it would not be too strong a conclusion to suggest that the UK Climate Change Act has failed even before it has gotten started. The Climate Change Act does have a provision for the relevant government official to amend the targets and timetable, but apparently not in the case of a failure to meet the targets. It seems likely that the Climate Change Act will have to be revisited by Parliament or simply ignored by policy makers. Achievement of its targets is simply and obviously not a realistic option.

Japan: A Genuine Clear-Water Climate Policy?

In June 2009 Japanese prime minister Taro Aso announced that Japan would seek to reduce its greenhouse gas emissions by 15 percent from 2005 levels by 2020. The prime minister said, "The target we are using is for 'genuine clear water' or *mamizu* as we say in Japanese—truly a genuine net effect of our effort to save and conserve energy."[12] The word *mamizu* is often used in Japanese politics when discussing the difference between, for example, actual budget cuts and those that might simply be tricks of accounting. In the context of climate policy a *mamizu* climate policy refers to purely domestic efforts, not counting on emission reductions accounted for using carbon offsets or land-use changes. It thus refers to explicit efforts to accelerate decarbonization of the Japanese economy.

Immediately upon announcing its proposed *mamizu* targets, the Japanese government was harshly criticized for its lack of commitment and vision. Yvo de Boer, director of the United Nations Framework Convention on Climate Change, commented that the commitment fell far short of what was needed, saying that the Japanese proposal left him speechless.[13] Facing a barrage of criticism, several weeks later Japan appeared to soften its stance on its *mamizu* climate policy when environment minister Tetsuo Saito announced that Japan would be willing to consider adding to its target by using international mechanisms such as offsets.[14] Further change in targets came in August 2009, when the Democratic Party of Japan (DPJ) unseated the Liberal Democratic Party (LDP), which had held power almost exclusively since 1955. The change in government was accompanied by a major change in Japan's proposed target for emissions reductions, which was dramatically increased to a 25 percent reduction from 1990 levels by 2020, equivalent to about a 37 percent decrease from 2005 values. Were either the LDP or DPJ emissions-reduction targets reasonable? Like the UK case, the analysis is as simple as it is sobering.

Figure 4.5 shows the actual rate of decarbonization of the Japanese economy from 1980 to 2006 as well as the rates of decarbonization implied by the 2020 and 2050 targets assuming an average 1.5 percent annual GDP growth. In 2006 Japan produced 0.42 metric tons of carbon dioxide for every $1,000 of GDP. To achieve an 80 percent reduction in its emissions from 1990 levels by 2050 implies that the carbon intensity of the Japanese economy would have to reach a level of 0.02 to 0.06 metric tons of carbon dioxide per $1,000 of GDP (for average annual GDP growth rates of 3 percent and 1 percent, respectively). Figure 4.5 also shows the decarbonization to 2020 implied by the *mamizu* (LDP) target of a 15 percent reduction in carbon dioxide levels from 2005 and the DPJ target of a 25 percent reduction below 1990 levels (for a 1.5 percent average GDP growth rate). The figure shows that the carbon intensity of the Japanese economy would have to reach a level of decarbonization about equal to that of France (in 2006) by 2014 or 2020, for the respective targets.

The rates of decarbonization of the Japanese economy implied by the targets can be seen in Table 4.2. These numbers are substantially higher than the rates of decarbonization observed from 1980 to 2006 and 2001 to 2006. Japan faced a range of criticism when it announced its 2020 *mamizu* target to reduce its domestic emissions by 15 percent from 2005 levels by 2020. Based on this analysis above, such criticism was unfounded for several reasons.

FIGURE 4.5 Historical and projected decarbonization of Japan's economy. Source: Author's calculations.

TABLE 4.2 Annual rate of decarbonization of the Japanese economy observed (first two columns) for 1980 to 2006 and 2001 to 2006, and implied (third and fourth columns) by the 2020 and 2050 targets of 15 percent of 2005 levels, 25 percent below 1990, and 80 percent below 1990, respectively (assuming 1.5 percent future GDP growth)

	1980–2006	*2001–2006*	*2007–2022*	*2007–2050*
Actual	–1.3 percent	–0.9 percent		
Implied by 15 percent reduction below 2005 by 2020			–2.6 percent	
Implied by 25 percent reduction below 1990 by 2020			–4.6 percent	
Implied by 80 percent reduction below 1990 by 2050				–5.4 percent

First, the rate of decarbonization implied by the 2020 target is twice its historical rate, implying substantial effort. Because no one knows how fast a major economy can decarbonize, there seems little point in arguing about proposed rates of decarbonization well outside that which actually has been possible. Policy implementation will be the ultimate arbiter of such proposals. There is essentially no qualitative difference between the Japanese and UK decarbonization targets, as in both instances the various targets imply a rate of decarbonization far outside the range of each country's experience for periods of a decade or longer. Both countries' targets appear unlikely to be met, though arguably the *mamizu* policy is more realistic than the UK Climate Change Act or the aggressive DPJ target.

Second, the rate of decarbonization in the Japanese 2020 targets is in excess of that which has been observed in any major economy in recent decades. However, Japan's experience during the early 1980s provides a notable exception: from 1980 to 1986 the average decarbonization of the Japanese economy was 4.4 percent per year. Vaclav Smil of the University of Manitoba argues that this achievement was due to a preponderance of "low hanging fruit" and is unlikely to be replicated, much less sustained, in the future (see Figure 4.3).[15] The shift in the Japanese economy from carbon-intensive industries, especially aluminum production, to less carbon-intensive industries also played an important role. Today, Japan is already one of the most carbon-efficient economies in the world, thereby making further gains more difficult and expensive than they would be in the generally less efficient economies of North America and Europe. Japan may be an important test case in the limits to efficiency gains as a strategy of decarbonization.[16] Thus, a *mamizu* approach to climate policy would provide valuable experience on how fast decarbonization rates might be accelerated.

An analysis by Professor Tetsuo Yuhara of the University of Tokyo explained the steps that Japan would need to take to meet the 25 percent reduction target below 1990 levels by 2020:[17]

1. Solar power generation must increase by 55 percent from current levels requiring photovoltaic cells to be installed in all new

houses and some existing houses (for a total of 600,000 installations annually).

2. Fifteen new nuclear power plants must be built and operated with 90 percent capacity rate (far above the current rate of 60 percent).
3. Increased thermal power from both gas power plants and biomass mixed combustion would be needed.
4. Ninety percent of sales of new vehicles must be of next generation vehicles (i.e., hybrid or electric cars).
5. All new houses and existing houses must have heat insulation installed, and mandatory energy conservation standards must be implemented.
6. The price of one ton of carbon dioxide would be 82,000 yen (~$80), compared to 15,000 yen (~$15) for the previous target of an 8 percent reduction, or the current price of around 7,000 yen (~$7).

These are undoubtedly ambitious (some might say impossible) goals. For instance, the proposal to deploy fifteen new nuclear power plants within a decade appears to stretch the bounds of credulity, even though Japan does have the third-most nuclear plants in the world (after the United States and France) and has plans to build more.[18] Japan's adoption of aggressive but impossible-to-achieve targets for emissions reductions signifies a desire to meet the symbolic needs of international climate politics while sacrificing the practical challenge of decarbonization policy. If Japan's *mamizu* targets were to be criticized, it should have been because they were too aggressive, not because they were too weak.

Australia: The Ups and Downs of an Emissions Trading Scheme

On December 12, 2007, Australian prime minister Kevin Rudd, having been sworn into office only the week before, gave a rousing speech at the Thirteenth Conference of the Parties to the United Nations Framework Convention on Climate Change, held in Bali, Indonesia.

Rudd explained that Australia was ready to commit to binding targets for emissions reductions. He promised to cut greenhouse emissions by 60 percent from 2000 levels by 2050. He had commissioned a study, known as the Garnaut Review, which was due in mid-2008. He insisted: "These will be real targets. These will be robust targets. And they will be targets fully cognizant of the science. . . . But it is not enough just to have targets. We have to be prepared to back them with sustained action—because targets must be, must be translated into reality. Australia will implement a comprehensive emissions trading scheme by 2010 to deliver these targets."[19] At Bali, Prime Minister Rudd was met with "long and loud applause."[20] However, despite signing the Kyoto Protocol as his first official act as prime minister and delivering the rousing Bali speech, Australia soon found itself facing international criticism for its failure to announce any short-term targets at the Bali meeting.[21]

Upon the release of an interim draft of the Garnaut Review in February 2008, its author, Ross Garnaut of the Australian National University, called for Australia to increase its targets beyond those mentioned at Bali: "Australia should be ready to go beyond its stated 60 percent reduction target by 2050 in an effective global agreement that includes developing nations."[22] Immediately thereafter, Prime Minster Rudd's government appeared to distance itself from the report. Climate Change Minister Penny Wong said of the report's conclusions, "We welcome Professor Garnaut's input. . . . [O]f course we will also be looking at other inputs, such as modelling from the Australian Treasury," prompting the leader of the Australian Green Party to complain that "Penny Wong has reduced Ross Garnaut to 'input.'"[23]

Less than two weeks after the draft Garnaut Review was released the Rudd government released a "green paper" outlining its initial plans for a Carbon Pollution Reduction Scheme, a policy based on a cap-and-trade approach to emissions reductions along the lines of the European Emissions Trading Scheme (ETS). A white paper outlining the final plans for the proposed CPRS was subsequently released in December 2008, as the Australian government announced an emissions-reduction target of between 5 percent (unilaterally) and 15 percent (in concert with other nations) below 2020 levels, and a proposed 60 percent reduction by 2050.[24] In the face of severe criticism for its lack of ambition,[25] the government justified its target in terms of the implications for per capita emissions, which it argued were on par with those promised by other nations. Before long, however, the Rudd government responded to its critics by raising its targets: in May 2009 the interim target was increased to a 25 percent reduction even as the proposed starting implementation date for the CPRS was delayed to 2011, justified on the need to allow the economy to regain strength in the aftermath of the global financial crisis.[26]

Regardless, in August 2009 the Australian Senate voted down the CPRS, prompting the government to split the renewable-energy provisions from the trading-scheme provisions. The renewable-energy package was subsequently passed into law. In November 2009 the opposition Liberal Party saw a revolt over the proposed CPRS, resulting in a change in party leadership and a second defeat for the trading scheme in the Senate. In the spring of 2010 the Australian carbon-trading scheme was delayed again, and the opposition party used the issue to gain support among the Australian populace. While debate over the ETS continues and its legislative future is uncertain, it is not too early to conduct an assessment of the various targets implied by the ETS. How realistic are Australia's proposed emissions-reduction goals in the short and long terms?

In 2006 Australia produced 0.84 metric tons of carbon dioxide for every $1,000 of GDP. Figure 4.6 shows the actual annual rate of decarbonization of the Australian economy from 1980 to 2006. The figure also shows the implied decarbonization for emissions-reduction targets of 5 percent, 15 percent, and 25 percent from 2000 levels by 2020 as well as for a 60 percent reduction by 2050, for an annual average 2.5 percent GDP growth rate.[27] The figure shows that the carbon intensity of the Australian economy would have to reach a level of about 0.10 metric tons of carbon dioxide per $1,000 of GDP by 2050, from 0.84 in 2006. The figure shows that the carbon intensity of the Australian economy would have to be cut by about a third to more

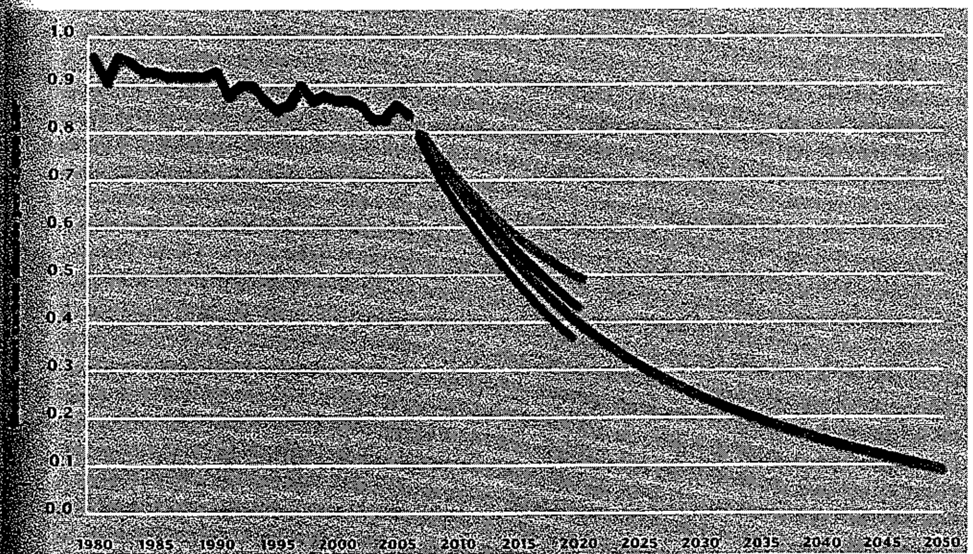

FIGURE 4.6 Historical and projected decarbonization of Australia's economy. Source: Author's calculations.

than half by 2020, depending upon assumptions, from its value of 0.84 in 2006.

The targets imply that Australia would have to achieve the 2006 emissions intensity of Japan by no later than 2018 for a 25 percent reduction target, by 2020 for a 15 percent reduction target, or by 2023 for a 5 percent reduction target (see Table 4.3). Japan has a highly efficient economy on several small islands with almost no domestic energy resources and operates a sizable number of nuclear power plants. Australia, on the other hand, burns much more coal and is generally profligate with carbon.

To think that Australia could achieve Japanese levels of decarbonization within the next decade strains credulity. This view was reinforced by Australia's climate change minister, Penny Wong, who commented on an earlier version of this analysis in February 2010, explaining that it neglected "the important role international permits will play in Australia's low cost transition to a low pollution future."[28] By "international permits" she was referring to carbon offsets, which are discussed in some depth later in the chapter. For now, what is important to

TABLE 4.3 Annual rate of decarbonization of the Australian economy observed (first two columns) for 1980 to 2006 and 2001 to 2006, and implied (third and fourth columns) by the 2020 and 2050 targets

	1980–2006	*2001–2006*	*2007–2020*	*2007–2050*
Actual	–0.5 percent	–0.7 percent		
Implied (5 percent reduction target, 2.5 percent GDP growth)			–3.8 percent	
Implied (15 percent reduction target, 2.5 percent GDP growth)			–4.6 percent	
Implied (25 percent reduction target, 2.5 percent GDP growth)			–5.4 percent	
Implied (60 percent reduction target, 2.5 percent GDP growth)				–4.8 percent

understand is that the use of "international permits" implies limited changes in the decarbonization of the Australian economy. They would not be, as the Japanese say, "genuine clear water."

Another way to look at the magnitude of the challenge of decarbonizing the Australian economy is in terms of its energy mix. It is straightforward to convert the energy mix into greenhouse gas emissions by multiplying the amount of energy consumed in quads by the amount of carbon emitted per quad for each fuel.[29] According to the U.S. Energy Information Agency, in 2004 Australia emitted about 391 million metric tons (Mt) of carbon dioxide from 5.3 quads of consumption, with the mix shown in Figure 4.7.[30] Multiplying the carbon dioxide generated per quad (shown in Figure 4.8) by the proportion of energy from each fuel source results in 390 Mt of carbon, essentially the same as that reported by the U.S. EIA.

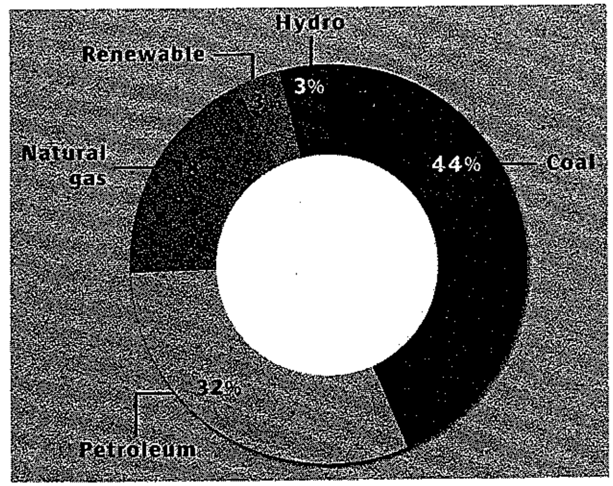

FIGURE 4.7 Australia's energy mix. Source: U.S. Energy Information Administration.

With this information it is then possible to perform a simple sensitivity analysis describing what it would take to decarbonize the Australian economy to a level consistent with a particular emissions-reduction target. In 2004 Australia produced 0.83 metric tons of carbon dioxide emissions per $1,000 (U.S.) (essentially the same as in 2006). To cut this amount in half over the next decade or less—as implied by the 5 percent, 15 percent, and 25 percent 2020 targets—would require that nearly all Australian coal consumption be replaced by a zero-carbon alternative such as nuclear or renewable energy. If an average nuclear plant provides 750 megawatts of electricity[31] and one quad is equivalent to 11,000 megawatts of electricity,[32] then about fifteen nuclear power plants would provide 1 quad. Coal provided 2.4 quads for Australia in 2004, meaning that it could be replaced by about thirty-six nuclear power plants.

Of course, Australia's energy consumption has increased since 2004 and is expected to increase in the future. If Australia's demand for energy increases by 1.5 percent per year to 2020, then an additional 1.4 quads of energy will be needed, implying the equivalent of twenty-one additional nuclear power plants, for a total of fifty-seven. These assumptions can be adjusted to explore the implications of aggressive

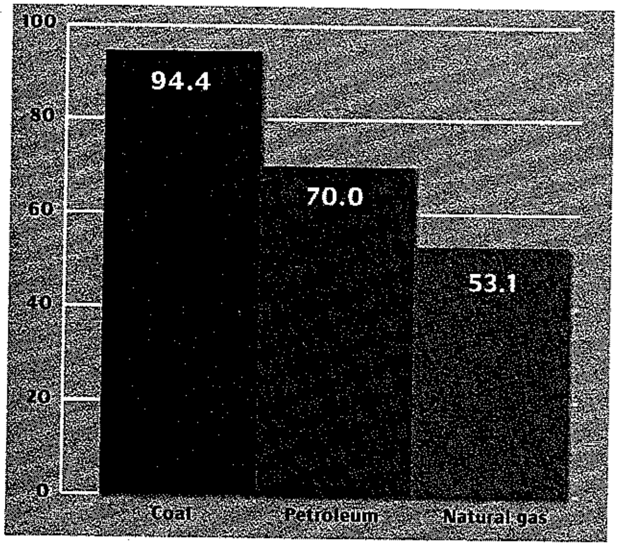

FIGURE 4.8 Million metric tons of carbon dioxide per quad of energy. Source: Calculated from data provided by the U.S. Energy Information Administration.

energy-efficiency programs or expansion of renewable-energy technologies (or other assumptions, such as the expansion of natural gas). For instance, if demand is held constant at 2004 levels and renewable energy constitutes 20 percent of the total 2004 energy mix, then only thirteen 750-megawatt nuclear power plants would be needed by 2020. Different assumptions will, of course, lead to different results, and the ones presented above are intended to be illustrative of the magnitude of the decarbonization challenge under a reasonable set of assumptions. The conclusion that the magnitude of the challenge is enormous is not particularly sensitive to these assumptions. If Australia relies on "international permits" to meet its emissions-reduction targets, as implied by its climate change minister, it would have to use the permits for the majority of the task, under any of the scenarios.

Several Australian readers of an early version of this analysis commented that a comparison of nuclear power plant equivalents, even if hypothetical, would not make much sense to many readers, because Australia has a long history of opposition to nuclear power plants—even building one plant would be an enormous achievement. The same sort of hypothetical sensitivity analysis can be conducted with technologies based on existing solar power plants. The Cloncurry solar thermal power plant in Queensland provides 10 megawatts of electricity.[33] If it operates at 33 percent efficiency, 1 quad of energy could be provided by 3,333 Cloncurry plants. Providing 3.8 quads implies 12,665 such plants, or about 24 plants coming online each week from 2010 to 2020.

What this sensitivity analysis clearly indicates is that to meet proposed emissions-reduction targets, Australia would need to undertake a herculean effort. The level of effort is daunting no matter what sort of technologies are used to illustrate the magnitude of the challenge, even if coupled with very aggressive efforts to increase efficiency and the use of renewable-energy sources. The use of offsets, as we will see, is an example of a sort of "magical thinking" that tends to show up in the climate debate rather than confront the real challenges of decarbonization. Regardless of the nature of the legislation ultimately adopted in Australia, the actual decarbonization of the Australian economy will all but certainly fall short of the proposed targets.

United States: Rejoining the Global Community

After years of U.S. disengagement from international negotiations under the Climate Convention during the presidency of George W. Bush, the Obama administration came into office in 2009 promising a renewed emphasis on climate policy. Subsequently, President Obama proposed a 14 percent reduction in 2020 emissions from a 2005 baseline, and legislation passed subsequently by the House of Representatives in the summer of 2009 mandated a 17 percent reduction. With the Senate not acting on climate policy in 2009, the United States proposed a 17 percent reduction in its carbon dioxide emissions (from a 2005 baseline) by 2020 at the UN climate negotiations in Copenhagen in December 2009. As of this writing the Senate has yet to pass any legislation in support of that goal, and all indications are that if any climate legislation is passed in 2010, it will not include provisions for a so-called cap-and-trade program. But whether it does or does not, the outcome with respect to emissions is all but certain to be much the same.

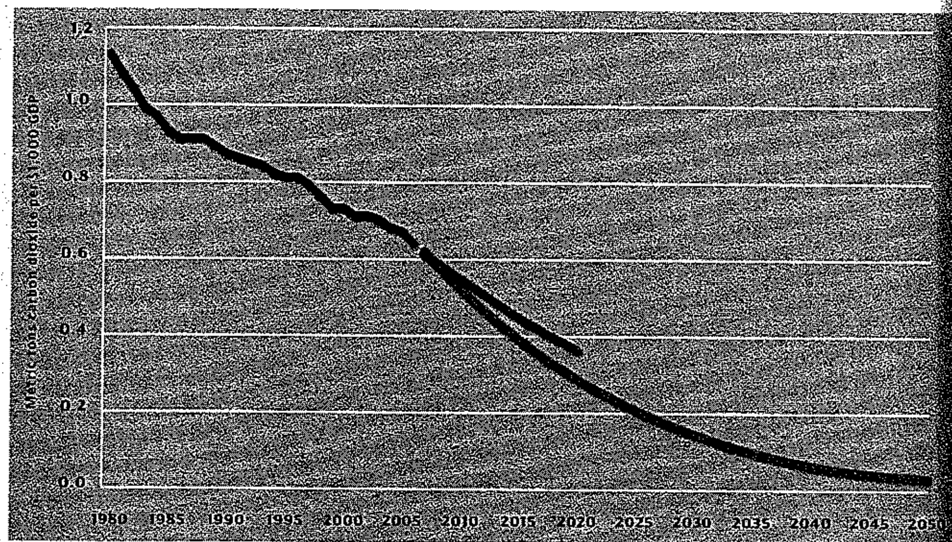

FIGURE 4.9 Historical and implied decarbonization of the U.S. economy. Source: Author's calculations.

By now the analysis is familiar. Like the United Kingdom, Japan, and Australia, the emissions-reduction target proposed by the United States at Copenhagen implies a massive level of effort. That level of effort is insensitive to a target that is a few percent larger or smaller. Figure 4.9 shows the decarbonization implied by a 17 percent reduction (from 2005) by 2020 and an 80 percent reduction (from 2005) by 2050.

The 17 percent reduction target implies achieving the carbon intensity of France by 2026, while the 2050 target implies achieving that level by 2019. What would such an achievement imply in practical terms?

Just as with Australia, the mathematics of U.S. carbon dioxide emissions are not complicated. In 2006 the United States consumed a total of 99.2 quads of energy. Achieving the carbon intensity of France would require that about 57 percent of 2006 coal energy (22.5 quads) be replaced by a carbon-free alternative. If these 12.9 quads were replaced by nuclear power (assuming a 750-MW nuclear plant, as above), this would imply a need for the equivalent of 189 new nuclear power stations. Because energy demand is expected to increase, new demand would also have to be met with a carbon-free alternative. Assuming a

0.5 percent annual increase in energy consumption implies a need for 10.4 new quads above 2006 values, or about an additional 153 nuclear power plants, for a grand total of 342! That seems rather unlikely.

We can perform other sorts of thought experiments with the simple math of emissions and decarbonization. In fact, this is exactly what climate policy experts do in a more complex and precise manner in the form of energy scenarios. To make emissions-reduction math work out in desired ways requires introducing a wide range of assumptions. However, making the scenarios analyzed more complex does not make meeting the challenge in the real world any easier than implied via the simple analysis presented here.

Consider a few examples of scenario analysis with the goal of reaching a 17 percent reduction target below 2005 carbon dioxide emissions in 2020:

Natural gas. Natural gas has been much discussed because it generates less carbon dioxide emissions than does coal for a given amount of energy. However, natural gas is not a long-term solution if the goal of mitigation policy is ultimately a reduction in emission of 80 percent or more. Consider a hypothetical case in which all present and future U.S. coal use is replaced by natural gas to 2020. Carbon dioxide emissions would be only 16 percent less than a 2005 baseline. Unless it is associated with some form of carbon capture and storage, using natural gas to pursue short-term goals would scuttle meeting long-term ones.

Very low carbon-energy sources. For wind and solar to displace enough coal to reach the 17 percent target by 2020 would require that they increase by a factor of twenty-five in absolute terms from their 2008 production of 0.61 quads.[34] Such an increase implies a need for about 200,000 2.5-MW wind turbines of the sort being deployed in West Texas as part of a 600-MW wind farm initiated in 2009 (and this analysis ignores nontrivial issues of intermittency of supply and energy storage and transport).[35] President Obama has expressed a goal of tripling wind- and solar-energy supply during his presidency.

Efficiency. Although there is undoubtedly potential to increase energy efficiency, to reach the 17 percent reduction from 2005 emissions would require a reduction of U.S. energy use by about 2 quads per year for the next decade, equivalent to the shutting down of about 20 power plants per year, ultimately reaching levels of energy consumption last seen in the late 1980s.[36] Assuming that policy makers and citizens want economic growth to continue, this would be a herculean task. With most estimates of future energy demand already assuming significant improvements in efficiency, the task could be even larger if these assumed gains do not occur or if economic growth happens at a faster rate than assumed.

In reality, of course, none of these idealized examples would be applied alone; accelerated decarbonization will require a combination of approaches. However, it is difficult to envisage a scenario that achieves the proposed reductions on the timescale implied by the targets. Achieving the equivalent of deploying more than 300 nuclear power plants in a decade is an enormous task no matter how the scenarios are put together.

Based on the data and analysis in Chapters 3 and 4, you are now empowered to do emissions-reduction math for yourself. Can you see a realistic way for the United States (or the UK, Japan, or Australia) to meet emissions reductions targets with existing technologies?

China, India, Europe, the Others in the Global Top 20, and the Bottom 193

The four countries examined in detail so far represent just under 30 percent of the total (as of 2006) global carbon dioxide emissions. What about the rest of the world?

No discussion of carbon dioxide emissions would be complete without discussing China and India, which were responsible for about 21 percent and 4.4 percent of 2006 emissions, respectively. Both countries are projected to be responsible for an increasing share of global emissions as their economies continue rapid growth. But from those countries' perspective—or indeed, from the perspectives of Brazil, Mexico,

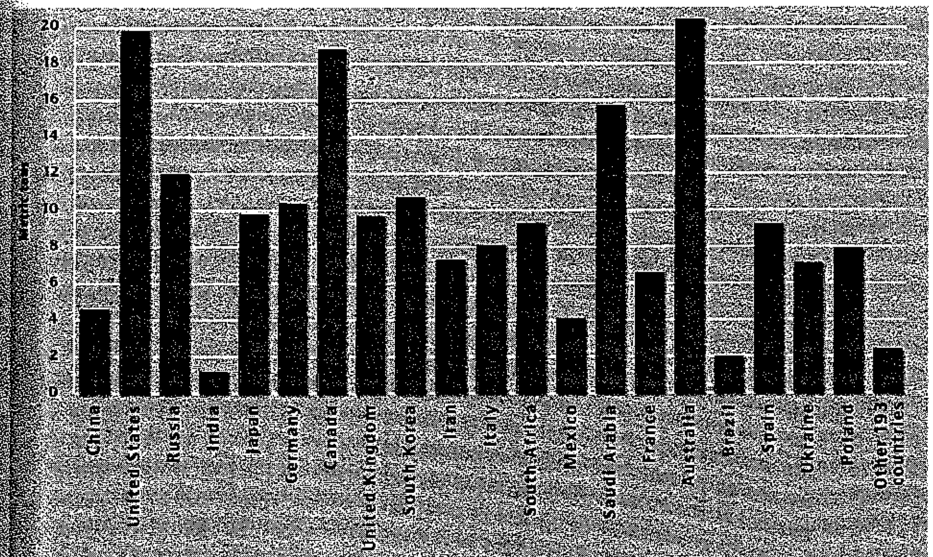

FIGURE 4.10 Per capita carbon dioxide emissions, 2006. Source: Author's calculations.

and the 193 countries outside the top 20 emitters—the mathematics of emissions look very different from a simple tabulation of total national emissions. Figure 4.10 shows the 2006 per capita emissions by country, with the largest total emitter on the left and the smallest on the right. The figure shows a marked difference in per capita emissions among countries often (and in some cases perhaps misleadingly) labeled as "developing" and those that are labeled as "developed." Consider that if China and India had per capita emissions in 2006 equal to that of France, with the lowest per capita emissions among developed countries, global emissions would have been about 30 percent higher. Putting Brazil, Mexico, and the 193 other countries at 2006 French per capita levels would add another 42 percent to 2006 levels.

Because economic growth is tightly coupled to emissions, as we saw in Chapter 3, many of the developing countries have been adamant that taking on emissions-reduction goals is simply not in the cards.[37] India has been particularly explicit about the primacy of economic growth. In summer 2009, Jairam Ramesh, the India environment minister, made this point without nuance: "India will not accept any emission-reduction target—period. This is a non-negotiable stand." The Indian prime minister told a domestic audience, "There is a lot of pressure on India and China on the issue of climate change. We have to resist it." Rajendra Pachauri, head of the IPCC and also an Indian, explained the underlying logic: "Obviously you are not going to ask a country that has 400 million people without a light bulb in their homes to do the same as a country that has splurge of energy."[38]

China has been much more circumspect than India in its statements about emissions reductions, but no less focused on the importance of economic growth. In 2009, for the first time, China's consumers bought more automobiles than consumers in the United States. China also saw more sales of desktop computers than did the United States, and the average size of newly purchased flat-panel TVs was larger.[39] China has explained that its "one-child" policy represents its contributions to international climate policy. Zhao Baige, vice minister of China's National Population and Family Planning Commission, asserted in late 2009 that China's one-child policy had prevented 400 million births that otherwise would have occurred, with dramatic implications for carbon dioxide emissions: "Such a decline in population growth leads to a reduction of 1.83 billion tons of carbon dioxide emissions in China per annum at present."[40]

More generally, both China and India have sought to present their "business as usual" policies as being aggressive climate policies that would remove any need to take on other obligations. For instance, both India and China have presented scenarios of their future emissions that suggest that they have already transitioned their economies to extremely high rates of decarbonization. In 2009 India released five business-as-usual projections including different assumptions of annual rates of decarbonization, from 1.0 percent up to 3.3 percent.[41] Four of these greatly exceed the 1987–2006 average annual rate of decarbonization of 1.1 percent. A single business-as-usual projection from the Chinese government released in 2009 suggested an annual rate of decarbonization of 6.5 percent per year to 2030, which is almost three times the 1987–2006 average.[42] China's emissions grew by 12.2 percent per year from 2000 to 2007, but under China's "business-as-usual" scenario growth is projected at only 2.5 percent per year to 2030.

If India and China have indeed already implemented policies that will decarbonize their economies by 3 percent per year and more, then it would be very good news indeed, as global rates of about 5 percent (or more) per year would be necessary to stabilize carbon dioxide concentrations at low levels, assuming modest economic growth.[43] However, some observers are rightfully skeptical about such claims. For example, the U.S. Energy Information Agency projects China's carbon dioxide emissions to double from its 2006 value to 12 Gt by 2030, whereas China's scenario projects an increase to only 7.5 Gt.[44]

With both India and China seeking to secure energy resources (of all types, including carbon-intensive energy resources) around the world, it seems highly unlikely that these countries have somehow discovered a secret to low-carbon growth that has escaped the United Kingdom, Japan, Australia, or the United States. With annual GDP growth expected to be 7 percent or higher per year in both countries, rapidly increasing carbon dioxide emissions seem a virtual certainty from China and India for years to come. To the extent that Brazil, Mexico, and the 193 other countries outside the top 20 emitters also seek rapid rates of economic growth, securing reliable energy supply will remain a priority with a focus on whatever energy supply can be secured at the lowest cost and greatest reliability.[45] This all but certainly will mean a continued reliance on carbon-intensive energy sources and rapidly increasing emissions from countries with large populations but relatively low emissions, such as Pakistan, Turkey, Indonesia, and Nigeria, as GDP growth continues.

The last major bloc of countries with significant emissions to discuss is Europe. Climate policy has been a core focus of policies of the European Union and many of its nations. Most notably, Europe has championed the 1997 Kyoto Protocol, which focused on reducing emissions below a 1990 baseline among industrialized countries. European officials and others (especially advocates for emissions trading) have argued that the Kyoto Protocol has been a success, resulting in lower emissions than might have otherwise occurred.[46] Others argue that the Kyoto Protocol has been a distraction. For example, Atte Korhola, professor of environmental change at the University of Helsinki, and Eija-Riitta Korhola, a member of the European Parliament, have argued that the

EU's climate policy "is expensive and flashy, yet bureaucratic and lacking results."[47]

Sorting through such claims and counterclaims about the successes or failures of Kyoto can be difficult, at best. But from the analysis in Chapters 3 and 4 we now know any policy focused on meeting aggressive emissions-reduction targets necessarily must result in an accelerated pace of decarbonization if it is going to contribute to meeting low stabilization targets. Decarbonization in the EU occurred at an annual average rate of 1.35 percent per year in the nine years before the Kyoto Protocol and 1.36 percent in the nine years following, suggesting that whatever effects the Kyoto Protocol may have had, accelerating decarbonization was not one of them during its first decade.[48] So while there are legitimate debates about what effect the protocol may have had on emissions and the degree to which counting reflects explicit acknowledgment of what was historically called "background" decarbonization, it seems unambiguous that through 2006 at least, the Kyoto Protocol did almost nothing to accelerate historical rates of decarbonization of the EU, much less raise those rates to levels needed to secure deep emissions cuts.

In many respects, climate policy is well suited to appeal to European geopolitical interests. With low rates of population growth (and population decline in some countries) and low economic growth, it is relatively much easier for Europe to achieve emissions reductions than it is for countries with high rates of population growth (like the United States) or fast-growing economies (like China or India). For Europe, business as usual results in declining emissions, especially when measured against a 1990 baseline, when emissions were much higher in grossly inefficient East Germany and before the UK "dash for gas." In 2006 David Miliband, UK secretary of state for environment, food, and rural affairs, explained why climate policy was a matter of EU interest:

> Europe needs a new *raison d'être*. For my generation, the pursuit of peace cannot provide the drive and moral purpose that are needed to inspire the next phase of the European project. The environment is the issue that can best reconnect Europe with its citizens and re-build trust in European institutions. The needs of the environment are coming together with the needs of the EU: one is a cause looking for a champion, the other a champion in search of a cause. . . . Climate change is the greatest challenge facing the world today. It cannot be met without the EU playing a leading role. The need to meet that challenge has the potential to bind European citizens together.[49]

But in important respects Europe has been no different from the United States, China, India, Japan, or any other country when it comes to sustaining economic growth while accelerating decarbonization—it has yet to figure it out. The iron law of climate policy holds as strongly in Europe as it does anywhere else. For instance, a spokesman for German chancellor Angela Merkel explained in 2008 why Germany wanted exemptions for certain industries from obligations to reduce emissions: "We've got to prevent companies from being threatened by climate-protection requirements."[50] In France in late 2009 a court found a proposed carbon tax unconstitutional because it exempted 93 percent of France's industrial emissions—the exemptions being necessary to win political support.[51] Following a subsequent defeat of the governing party in regional elections during the spring of 2010, French president Nicolas Sarkozy withdrew the proposed carbon tax altogether. When the trade-off is emissions reductions versus economic growth, the economy wins every time. Europe has demonstrated admirable diplomatic and symbolic leadership on climate policy, and its efforts to implement the Kyoto Protocol provide a valuable body of practical experience. Nevertheless, Europe's experiences mirror those around the world.

The bottom line from this survey of decarbonization policies around the world is straightforward: no one knows how fast a large economy can decarbonize, much less the entire global economy. Efforts to implement decarbonization policies will be better off by realizing this uncomfortable reality.

Magical Solutions and Their Consequences

The discussion and analysis in this chapter have thus far largely ignored the various and complex mechanisms of climate policy, such as those embodied in emissions trading, carbon taxes, or other instruments. The simple math of decarbonization illustrated through the preceding brief global tour shows clearly that whatever mechanism is proposed, it all but certainly cannot achieve the aggressive short-term targets set forth in climate policies in countries around the world. Rather than serving as policy targets against which politicians expect to be held accountable, emissions-reduction goals are thus to be viewed as aspirational targets that set forth a desirable but practically unachievable goal, like ending poverty or achieving world peace.

Some believe that aspirational targets are useful because they orient action in a desired direction, regardless of the pace of change. However, a risk of proposing aspirational goals is that policy makers will look for ways to avoid meeting the objectives while maintaining the appearance of accountability to formal goals, at least during their time in office. Stanford's David Victor explains the risk in the context of international climate policies: "Setting binding emission targets through treaties is wrongheaded because it 'forces' governments to do things they don't know how to do. And that puts them in a box, from which they escape using accounting tricks (e.g., offsets) rather than real effort."[52] In other words, policy makers will look to "magical solutions" that have symbolic effects but little else.

The "magical solution" to reducing carbon dioxide (and other greenhouse gas) emissions that has received the most attention is emissions trading, often known as cap and trade. Cap and trade operates under a seductively simple mechanism. Permits or allowances to emit are issued in some manner (e.g., through an auction or given away), and a market is created to allow them to be traded. A limit is set on the number of allowances available—the cap—which declines over time to some targeted value, such as a 17 percent reduction by 2020 or 80 percent by 2050. The cost of the traded allowances places a price on emissions that is set by the market, and as allowances become more scarce, the price will rise, encouraging innovation in energy technologies leading to declining carbon and energy intensities. Such trading, it is argued, will enable emissions reductions to take place where they are most efficient, as determined by the market mechanism.

Cap and trade sounds great. The problem is that it cannot work. It cannot work because it runs smack into the iron law of climate policy. As argued in Chapter 2, when emissions reductions run up against economic growth, economic growth will win out. From the perspective of the Kaya Identity—which describes the interplay of emissions, the economy, and technology—we can see that if we do not have all the technologies we need to quickly accelerate rates of decarbonization of the economy, the only other driver of emissions reductions is a reduction in GDP. Yet if a reduction in GDP is not politically possible, then what necessarily must give way is the commitment to reducing emissions. This logic means that emissions will continue to rise, even in the presence of a cap-and-trade program if technologies are not ready at scale to rapidly accelerate decarbonization.

Indeed, any effort to put a price on carbon, whether by a tax or via a cap-and-trade program, will face the same problem. Putting a high price on carbon causes economic pain and discomfort to energy consumers, who also happen to be citizens and, often, also voters. Politicians who want to continue in their jobs spend every waking hour trying to protect their constituents from economic pain. They will not rush to cause it intentionally. To think that politicians are going to willingly impose discomfort or pain on their constituents is fanciful at best.

The only way for a binding cap on emissions to not cause economic discomfort is if cap-and-trade programs are designed intentionally to have a loose or nonexistent cap, to allow economic growth to continue unaffected by the program—what might be called a nonbinding binding cap. A popular mechanism for loosening an emissions cap is through the use of "offsets," which are allowances introduced into a trading system through the reduction of emissions (or future emissions) in some distant geographical or economic location, allowing business as usual to proceed at home.

For instance, in 2009 Germany's environment minister, Sigmar Gabriel, explained that Germany needed eight to twelve new coal plants in order to meet demand while closing much hated nuclear power stations. Of the increased carbon dioxide Gabriel explained that through emissions trading, "You can build a hundred coal-fired power plants and don't have to have higher carbon-dioxide emissions."[53] Emissions trading, it seems, can work magic. In the United States congressman Rick Boucher (D-VA) expressed a similar preference for magical solutions when explaining how cap-and-trade legislation would secure a future for coal: "We provide two billion tons of offsets each year during the life of the program . . . [to be used by utilities] in forestry, agriculture and projects like tropical rain forest preservation in order to meet their carbon-dioxide reduction requirements under legislation. Therefore, they can comply with the law while continuing to burn coal."[54] Similarly, we saw Penny Wong, Australia's climate change minister, explaining earlier in this chapter how offsets would allow Australia to meet its targets for emissions reductions.

If so-called carbon offsets only allowed evasion of emissions-reduction targets, they would be bad enough. However, offsets have deeper problems. For instance, a waste product called HFC-23 results from the production of an industrial chemical used in air conditioners and some plastics.[55] HFC-23 is also a very potent greenhouse gas. Companies in China and India discovered that they could be paid by Europeans (under a Kyoto Protocol program called the Clean Development Mechanism, or CDM) to destroy the gas, which is easy to do and inexpensive. Perversely, according to Michael Wara of Stanford University, "the sale of carbon credits generated from HFC-23 capture is far more valuable than production of the refrigerant gas that leads to its creation in the first place," which had the effect that "refrigerant manufacturers were transformed overnight" into carbon-credit manufacturers with a side business in industrial chemicals. While the HFC-23 scam was identified and steps were taken to correct it (after some €4.7 billion were transferred from Europe), other perverse outcomes from emissions trading routinely surface. For instance, in late 2009 the Chinese government was accused of manipulating wind-farm subsidies so that the projects would be eligible to receive investment from Europe and generate carbon credits.[56] Many of these projects would have occurred without the European investment of more than $1 billion, despite the fact that the explicit goal of the CDM is to encourage the pursuit of less-carbon-intensive projects that would not have been built otherwise.

Even with the many failures, inefficiencies, and outright corruption demonstrated to result from cap-and-trade programs, they are unlikely to disappear anytime soon from the climate-policy landscape. Cap-and-trade advocates have invested an enormous amount of social and political capital into carbon trading. While the dismal outcome of Copenhagen in December 2009 represented a setback, for many advocates it was simply cause to try yet again. A second reason why carbon trading is not going away is more fundamental: there is an enormous amount of money involved, with an almost unlimited potential for carbon traders to make huge profits whether emissions actually go up or down. As we have seen, economic incentives are a powerful motivator. A final reason cap and trade is unlikely to go away is that some involved in the international process care more about promises than actual performance. When asked if it mattered whether Australia had passed emissions-trading legislation in time for the 2009 Copenhagen meeting, the head of the United Nations Framework Convention on Climate Change responded: "Quite honestly, no. What people care about in the international negotiations is the commitment that a government makes to take on a certain target."[57] When the focus is exclusively on ends to be achieved, the fidelity of the means employed can easily be overlooked, and magical solutions are the result.

The approach of setting an emissions target and timetable, allocating emissions permits, and then saying that the magic of the market will efficiently take care of the task is exactly the sort that one would expect if one doesn't have a good answer to the challenge of decarbonization. Markets cannot make the impossible possible, and when they are used in such a manner, they often have undesirable results.

Lessons Drawn from Decarbonization Mathematics

The bottom line of Chapters 3 and 4 is that no one really knows how to accelerate the decarbonization of large economies. The various comprehensive policies that have been put into place and proposed are clearly not up to the task, based on some very simple mathematics. One reason for this outcome is an inability to recognize those assumptions that many people "know for sure, but just ain't so" (see Chapter 2). The implications of this uncomfortable reality are not to throw up one's hands and give up. Far from it. The implication is that climate policy must proceed starting with a clear-eyed view of our policy ignorance. In such a context policy progress with respect to goals is most likely to occur with a diversity of policies that are incremental, carefully evaluated with successes scaled up and failures terminated. The design of such climate policies that might perform better is a subject that I'll return to in Chapter 9.

The climate issue is full of various authorities proclaiming this or that. Why is my argument any different? Why should you believe me? The short and simple answer is that you should not just believe what I say. You should do the math yourself. And based on the data and simple methods described in these two chapters, now you can.[58]

Figures 4.11 and 4.12 show the energy consumption mix for the top 20 global emitters in 2006 based on data provided by the U.S. Energy Information Agency and the European Environment Agency.[59] Using this information one can easily calculate total emissions for each country based on the carbon intensities of the different fuel sources. For 2006 this simple method of calculating emissions can reproduce the 2006 EIA country aggregates for the top 20 emitters to within less than a 2 percent error. These data then allow one to perform a wide range of sensitivity analyses related to how nations might hypothetically change their consumption of energy.

Table 4.4 shows the equivalent energy generation necessary to replace 10 percent of consumption for each of the top 20 countries as well as for the other 193 other countries, in terms of nuclear power stations (like Dungeness B in Kent, England), solar thermal plants (like Cloncurry in Queensland, Australia), and wind turbines (of the type being installed in West Texas).[60] For instance, the table shows that replacing 10 percent of Iran's 2006 energy consumption would require more than 11 new nuclear power stations or more than 2,500 solar thermal plants or more than 10,000 wind turbines. A reduction in consumption of 10 percent would have the same effect. One is quickly jarred back to reality when one considers the geopolitics of nuclear energy in the context of Iran. How is Iran to decarbonize?

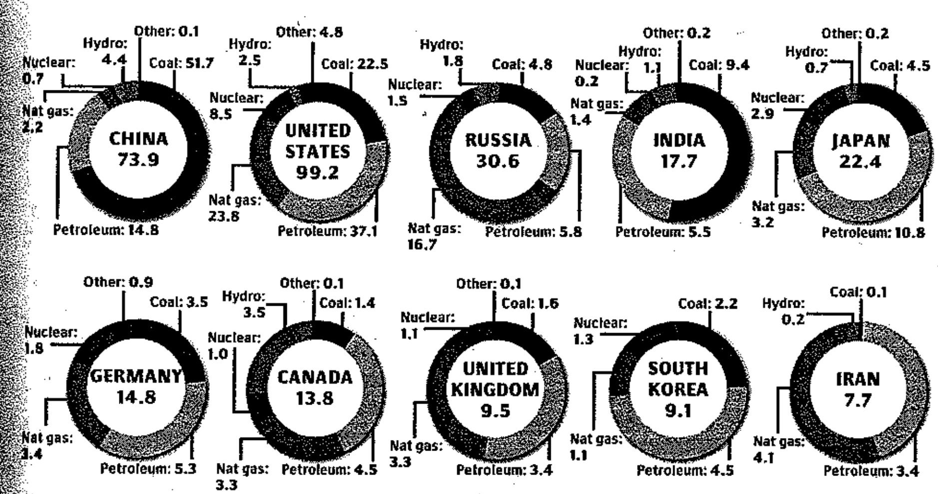

FIGURE 4.11 Breakdown of energy consumption (quads), top 1–10 global emitters of carbon dioxide.

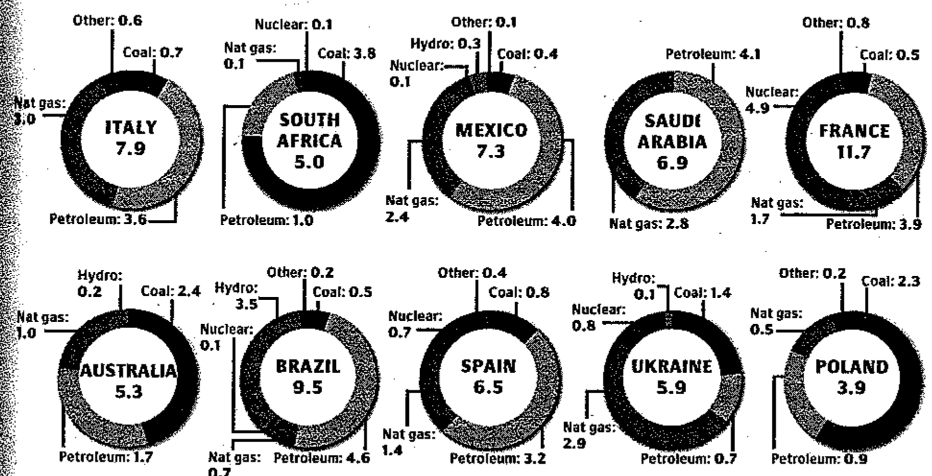

FIGURE 4.12 Breakdown of energy consumption (quads), top 11–20 global emitters of carbon dioxide. Source: U.S. Energy Information Administration and European Environment Agency.

These data can also be used to develop scenarios for emissions reductions. For instance, for the world to achieve a 50 percent reduction in its emissions below a 1990 baseline it could do the following. First, the world would need to eliminate all coal and natural gas consumption in 2006 and replace it with nuclear power stations. This could be

TABLE 4.4 Equivalent energy infrastructure

				Equivalent Energy Generation		
	Quads of Energy Consumed 2006	*10 percent of 2006 Consumption*	*10 percent of 2006 consumption in Gigawatts*	*Nuclear Plants*	*Solar Thermal Plants*	*Wind Turbines*
1 China	73.8	7.4	81.2	108.2	24,600	97,807
2 United States	99.2	9.9	109.1	145.5	33,067	131,470
3 Russia	30.3	3.0	33.3	44.4	10,100	40,157
4 India	17.7	1.8	19.5	26.0	5,900	23,458
5 Japan	22.6	2.3	24.9	33.1	7,533	29,952
6 Germany	14.6	1.5	16.1	21.5	4,876	19,388
7 Canada	14.0	1.4	15.3	20.5	4,650	18,488
8 United Kingdom	9.8	1.0	10.8	14.4	3,267	12,988
9 South Korea	9.0	0.9	9.9	13.2	3,000	11,928
10 Iran	7.7	0.8	8.5	11.3	2,567	10,205
11 Italy	8.1	0.8	8.9	11.8	2,690	10,694
12 South Africa	5.0	0.5	5.5	7.3	1,667	6,627
13 Mexico	7.4	0.7	8.1	10.8	2,452	9,750
14 Saudi Arabia	6.9	0.7	7.6	10.1	2,297	9,133
15 France	11.4	1.1	12.6	16.8	3,815	15,168
16 Australia	5.3	0.5	5.8	7.8	1,767	7,024
17 Brazil	9.6	1.0	10.6	14.1	3,212	12,769
18 Spain	6.5	0.7	7.2	9.5	2,170	8,628
19 Ukraine	5.9	0.6	6.5	8.7	1,967	7,819
20 Poland	3.9	0.4	4.3	5.7	1,300	5,169
Other 193 countries	103.3	10.3	113.6	151.5	34,438	136,922
2006 World total				692.3	157,333	625,542
2030 added demand (at 1.5 percent annual demand increase)	206.0	20.6	226.6	302.1	68,667	273,012

Information on equivalent energy generation

	Gigawatts			
Nuclear Plant	0.75	1 GW at 75 percent efficiency	Dungeness B	Kent, England
Solar Thermal	0.0033	10 MW at 30 percent efficiency	Cloncurry 10MW	Queensland, Australia
Wind Turbine	0.00083	2.5 MW at 30 percent efficiency	West Texas 2.5 MW	

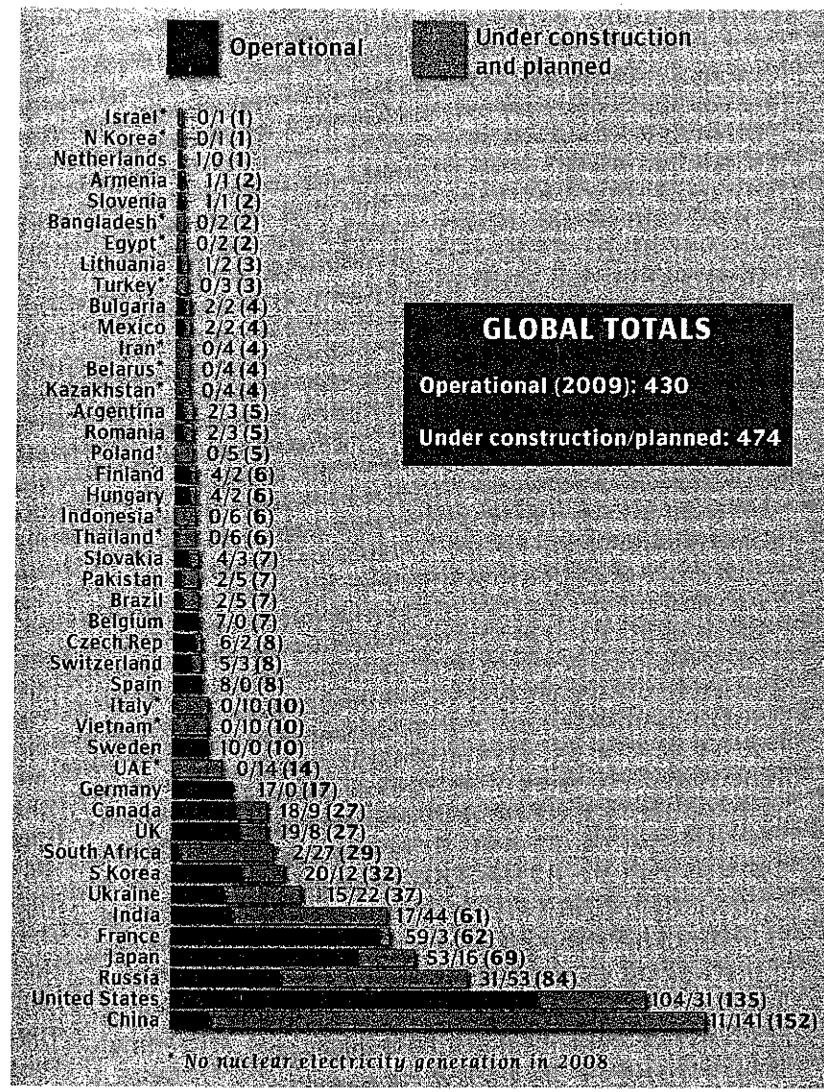

FIGURE 4.13 The global nuclear family: Distribution of reactors. Source: *Financial Times.*

done by adding about 2,800 new nuclear power plants. But that would not be enough to meet the target. More than 40 percent of 2006 petroleum consumption would also have to be replaced (e.g., perhaps by using electric vehicles), necessitating about another 750 nuclear power stations. But then there will be new demand beyond 2006 that has to be met. If global consumption of energy increases by 1.5 percent per year to 2050, that will imply a need for more than 340 new quads of energy, which, if met by nuclear power plants, implies another 5,000 nuclear power stations. The grand total? More than 12,000 nuclear power stations' worth of effort would be needed to reduce emissions to 50 percent of their 1990 level by 2050.[61] If we were to add in consumption needed to provide electricity to the 1.5 billion people in 2009 without access, it would necessitate the equivalent of thousands more nuclear stations.

These numbers are so large as to still remain a bit abstract. Figure 4.13 shows the total number of nuclear stations operating or in the planning stages as of 2009. Creating sufficient carbon-free energy by 2050 to reduce emissions by 50 percent below 1990 levels requires a level of effort equivalent to dozens of times greater than has been invested in nuclear energy to date. How many nuclear power stations is 12,000? It is, in round numbers, about the same as one new plant coming online every day between now and 2050, a result that is not new; climate scientist Ken Caldeira and his colleagues made that argument in 2003.[62]

A clear-eyed look at the simple mathematics of decarbonization and emissions reductions can be sobering, but also revealing. It need not imply that the task of accelerating decarbonization is impossible; rather, it sets the stage for a more realistic consideration of policies that might work better than those that have dominated the climate debate. But before further engaging issues of policy design for decarbonization, we have to ask: What if the decarbonization challenge proves too great? What then? Is there a backstop or Plan B? That is the subject to which we next turn.

CHAPTER 5

Technological Fixes and Backstops

THE DISCUSSION SO FAR suggests that policies now being contemplated by governments around the world to decarbonize their economies in coming years and decades are almost certainly going to fall far short of their goals. What happens if it turns out that despite the best intentions and effort, concentrations of carbon dioxide continue to increase to levels that policy makers and the public deem to be unacceptable? Recent discussions of climate policies have increasingly emphasized "geoengineering" of the global Earth system.

In January 2009 *The Independent*, a newspaper in the United Kingdom, asked eighty climate experts if the dismal performance of mitigation policies meant that a "Plan B" was now needed. The "Plan B" referred to by *The Independent* was "research, development and possible implementation of a worldwide geoengineering strategy." More than half responded in the affirmative.[1]

Geoengineering has come to mean a range of different things, and pinning down a definition is an important first step to deciding whether it's something we ought to pursue. In 2009 the American Meteorological Society defined geoengineering as "deliberately manipulating physical, chemical, or biological aspects of the Earth system" with a focus "on large-scale efforts to geoengineer the climate system to counteract the consequences of increasing greenhouse gas emissions." The AMS recognized that geoengineering overlaps with policies focused on both adaptation and mitigation: "To the extent that a geoengineering